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Application of a Regional Sediment Budget Analysis System for Florida's East Coast

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ABSTRACT

This paper develops preliminary regional sediment budgets for the Northeast and Central regions of the East Coast of Florida as part of "proof-in-concept" testing of Version 2 of the Sediment Budget Analysis System (SBAS2000). Features of SBAS2000, a PC-based method for calculating sediment budgets for local and regional extents that may encompass multiple inlets and beaches, are illustrated through the application. The paper concludes with recommendations for improving regional sediment budget analyses.

INTRODUCTION

Construction, operation, and maintenance of major navigation projects along the coast of the United States began more than 150 years ago. Today, the coastal response to these projects may extend beyond local project authority and dimensions. In addition, subsequent projects have each had their individual impacts, creating a cumulative and complex signal that must be understood to effectively manage limited sand resources. A regional sediment management plan, including a regional sediment budget, can encompass the spatial impacts of each project and provide a model for making informed decisions.

The Coastal and Hydraulics Laboratory (CHL) of the U.S. Army Engineer Research and Development Center is conducting research aimed towards improving the U.S. Army Corps of Engineer's ability to estimate region-scale impacts. The aim of the R&D is to develop products that will reduce cost of the design, construction, operation and maintenance of the nation's beaches. As a part of this effort, an upgrade to the Sediment Budget Analysis System (SBAS2000) was developed for regional application, and was applied to Florida's East Coast as part of a proof-in-concept evaluation.

The East Coast of Florida is an ideal site for rudimentary exercising of SBAS2000. The region considered in this study extends 240 miles from the

Florida-Georgia border at the north to Jupiter Island at the south, encompassing 11 inlet and channel entrances. Inlet Sediment Budgets (ISB) are available for nearly all these inlets, providing initial input for testing SBAS2000. In addition, engineering activities pertinent to a sediment budget are plentiful within this populated region, including dredging and dredged material placement, sand bypassing, and beach fill construction. Shoreline position and beach profile data to document beach change and provide the adjoining data sets between adjacent ISBs are available from the Florida Department of Environmental Protection (FDEP) web site.

This paper has three goals. First, it provides a summary of the capabilities of SBAS2000 that were refined through application to Florida's East Coast. Second, it presents preliminary regional sediment budgets for the Northeast and Central regions of the coast, which should be of interest to local communities and the State. Third, it summarizes regional issues that precipitated through this application and which are deemed important for future research and development of SBAS2000. It is emphasized that the Northeast and Central regional sediment budgets are preliminary and serve as a rigorous evaluation data set for exercising and improving SBAS2000. The regional sediment budgets presented herein do not reflect the official views of the Corps or the FDEP.

REGIONAL CONCEPTS

Development of regional sediment budgets is an integral component to the implementation of a systems approach in the management of Florida's beaches. The Jacksonville District of the U.S. Army Corps of Engineers and the FDEP have developed a partnership to promote regional approaches to beach management which recognize sediment transport boundaries rather than political boundaries in the management of sediment resources. This regional sediment management approach endeavors to exploit opportunities for linking activities involving shore protection, navigation and environmental restoration projects.

Florida Statutes Sections 161.088 and 161.091 provide for increased State funding for those projects that facilitate cost savings through economies of scale. The FDEP is directed to develop a management strategy that, among other things, encourages regional approaches, maximizes infusion of beach-quality sand into the system, extends the life of beach nourishment projects, and promotes inlet sand bypassing (Leadon 1999). The Corps has also recognized the potential for project cost savings through coordination of projects on a regional scale. Regional sediment management demonstration projects are currently being formulated in a number of coastal Corps Districts to investigate the long-term merits of a systems approach to coastal project management. Regional sediment budgets identify the magnitudes, pathways, and sources and sinks of sediment through analysis of survey data, and numerical and analytic model results. Regional sediment budgets developed in coordination with detailed sand source inventories will help in making informed sediment management decisions in shaping the future of Florida's beaches.

REGIONAL SETTING

The Northeast and Central regions considered in this paper extend approximately 240 miles from the Florida-Georgia border south to Jupiter Island (Figure 1). Of the 11 inlets in this region, 9 have been modified by structures such as jetties, groins, revetments and seawalls. The remaining two "natural" inlets are Nassau Sound and Matanzas Inlet. As indicated by the ISBs reviewed in this study, dredging activities associated with maintenance of navigation channels along Florida's east coast results in the excavation of approximately 320,000 cu yd of littoral sediment per year. Beach fill placement is estimated to be nearly 1.3 million cu yd per year (Valvedere et al 1999). The regional sediment budgets presented in this paper incorporated these sediment sources and sinks where possible.

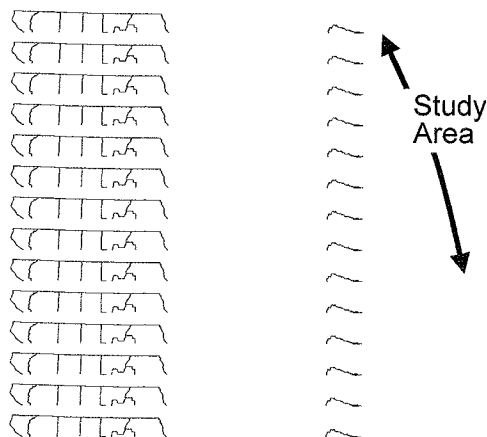


Figure 1. Study area

Stauble (1993) characterized Florida's Atlantic coast into three regions as follows:

- Northeast Florida with barrier islands backed by low tidal marshes (separated by six inlets)
- Central Florida with the Indian River Lagoon system of narrow barriers and Cape Canaveral (four man-made inlets)
- Southeast Florida consisting of mainland beaches in the north and narrow barrier islands in the south (bisected by ten inlets)

Following the geologic differentiation discussed by Stauble (1993), the FDEP delineated three regions (Northeast, Central and Southeast) along Florida's East Coast based upon physical processes rather than political boundaries (Table 1).

Table 1. FDEP Atlantic Coast Regions		
Northeast (~105 miles)	Central (~132 miles)	Southeast (~91 miles)
Sea Islands St. Johns Beaches Flagler/Volusia Beaches	Cape Canaveral Indian River Coast St. Lucie Beaches Treasure Coast	Northern Palm Beaches Palm Beaches Southern Palm Beaches Broward/Dade Beaches Southern Barriers

Descriptions of the subregional breakdowns can be found in the Strategic Beach Management Plans (FDEP 1999). These plans have been developed to guide the execution of Florida's beach management program with a legislated regional approach.

SEDIMENT BUDGET METHODOLOGY

A sediment budget is a tallying of sediment **gains** and **losses**, or **sources** and **sinks**, within a specified control volume (or cell), or series of connecting cells, over a given time. There are numerous ways of formulating a sediment budget (e.g., Shore Protection Manual 1984, Jarrett 1991, Bodge 1999). A balanced sediment budget yields an integrated picture of sediment (typically sand) motion, associated beach change, dredging and infilling of a navigation channel at inlets, and other engineering activities within the reach covered by the analysis. Typically, the most reliable data available form the foundation for the sediment budget, and lesser-known or more uncertain parameters are calculated to balance the budget by applying the principle of conservation of mass of sand (converted to volume or volumetric rate). A balanced sediment budget is a valuable tool for investigating observed coastal change and for forecasting the overall future state of the coast and consequences of management alternatives. Examination of an unbalanced sediment budget provides basic and useful information about the coastal system. An unbalanced budget may indicate a deficiency in the data set forming the budget (Dolan et al 1987), reveal a misunderstanding in certain physical processes and assumptions (Inman 1991), or give bounds on the uncertainty range for the data sets.

Uncertainty consists of error and true uncertainty. A main general source of error is limitation in the measurement process or instrument. True uncertainty is the error contributed by unknowns that may not be directly related to the measurement process. In coastal processes, significant contributors to true uncertainty enter through natural variability such as (1) temporal variability (daily, seasonal, and annual beach change), (2) spatial variability (alongshore and across shore), (3) selection of definitions (e.g., shoreline orientation, direction of

random seas), and (4) unknowns such as grain size and porosity of the sediment (especially true in placement of dredged material) (Kraus and Rosati 1999).

A balanced sediment budget represents the difference between sediment sources and sinks in each cell equal to the rate of change in sediment volume occurring within that region, accounting for pertinent engineering activities. The sediment budget equation can be expressed as

$$\sum Q_{source} - \sum Q_{sink} - \Delta V + P - R = Residual \quad (1)$$

in which all terms are expressed consistently as a volume or as a volumetric change rate, Q_{source} and Q_{sink} are the sources and sinks to the control volume, respectively, ΔV is the net change in volume within the cell, P and R are the amounts of material placed in and removed from the cell, respectively, and *Residual* represents the degree to which the cell is balanced. Alternatively, values for ΔV , P , and R may be represented as sources or sinks to the cell, depending on convention.

For a balanced cell, the residual is zero. For a reach of coast consisting of many contiguous cells, the budget for each cell must balance in achieving a balanced budget for the entire reach. The residual term in Eq. 1 allows the user to explore the consequences of adding, removing, changing the magnitude of, or changing the pathways of sources, sinks, and engineering activities within the Sediment Budget Analysis System (SBAS). A *macro-budget* is defined as a budget of all cells, including all sources and sinks, and must be balanced before individual cells can all be balanced.

The SBAS is a PC-based method for calculating single or multiple inlet and adjacent beach sediment budgets, and runs on the Windows 95, 98 and NT platforms. Some of the primary capabilities of SBAS are:

- Automatically generates and updates Eq. (1) as the user defines cells and transport pathways with the SBAS toolbar menu
- Allows different sediment budgets for the same coastal reach to be copied and modified to bracket seasonal, yearly, project-specific, and historical changes, and to reflect uncertainty and sensitivity testing

- Color-coding of cells indicates whether cells have a surplus, deficit, or are balanced
- Facilitates a regional approach through limitless number of cells and transport pathways, and page scrolling left and right, or up and down
- Allows the user to keep an accounting of uncertainty and the sediment budget imbalance within each cell and within the macro-budget
- Provides capability to calculate transport rates based on other parameters
- Allows non-referenced images (e.g., photographs, bitmaps, etc.) to be loaded as background wallpaper with the sediment budget
- Tutorial, example project, and help files provide on-line guidance

SBAS2000 is a significant upgrade that adds the following capabilities to the original version:

- Allows user to input and utilize various types of geo-referenced images
- User can zoom-in and zoom-out on the image and sediment budget elements
- Allows user to graphically define baselines
- Provides a spreadsheet interface for user to input volumetric or shoreline changes as a function of baseline position
- Includes an option to plot the variation of volumetric and shoreline change rates with baseline position, displayed over the geo-referenced image
- Provides ability to place photographic images of selected budget areas over geo-referenced images

These new enhancements were tested and improved through formulation of the Florida-East regional sediment budgets.

REGIONAL SEDIMENT BUDGETS

Overview

The Florida-East regional sediment budgets were formulated for each region listed in Table 1 using the ISBs available in the literature, shoreline position data, and beach and dredged material placement records. Each ISB considered beach change and engineering activities for the adjacent beaches within the immediate influence of the inlet, as shown in Figure 2. Between adjoining ISBs, shoreline position data, beach fill, and dredged material placement records were used to formulate sediment budgets for the "Connecting Beach" region. "Meso-

budgets" for each ISB and connecting beaches were formulated, as well as a macro-budget for the entire region. The meso-budgets were constructed on a sub-regional (inlet and adjacent beaches, or connecting beach) scale, whereas a macro-budget was formed of several to many meso-budgets.

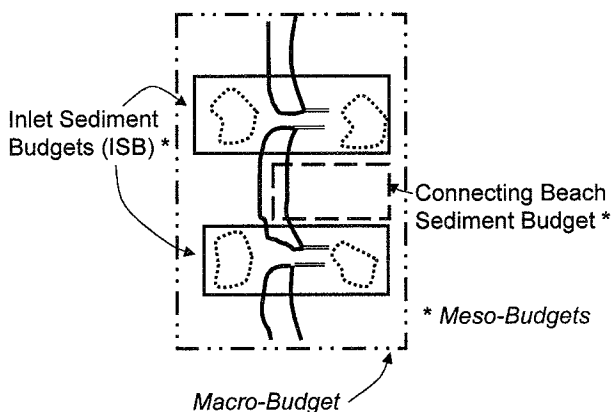


Figure 2. Definition of terms for regional sediment budgets

Connecting beach budgets were formulated through consideration of shoreline changes (defined as 0-ft elevation relative to National Geodetic Vertical Datum (NGVD) 1929) for a targeted period-of-record (from the early 1970's through the late 1990's). The shoreline change rates (as derived from the FDEP shoreline database available online at http://www.dep.state.fl.us/beach/his_shor.htm) were converted to volume change rates for incorporation into the regional sediment budgets by applying a representative value of 1 cubic yard per foot of shoreline change. This conversion implies that the beach profile from the berm crest to the depth of closure, assumed to be 27 ft in elevation, translates landward or seaward while retaining the same shape. Artificial placement of material into the littoral system through beach nourishment, sand bypassing and various other methods were identified and incorporated into the regional budget as tabulated by Valverde et al (1999). For comparison with volume changes calculated with the shoreline position data, volume changes were also calculated

using the average end method from beach profile data for Dade county for the same time period.

Methodology

Sediment budget sources and sinks were summarized for each meso-budget using the notation defined by Eq. 1. Because this study was an initial assessment and compilation of the available data, the *Residual* term was allowed to float. Large positive and negative values of the *Residual* give an indication of those meso-budgets for which additional analysis is required. For the Northeast and Central regions indicated in Table 1, a macro-budget was formulated. The results of the analyses are discussed in the next section.

Results

Tables A1 and A2 located in the Appendix present the meso- and macro-budgets for the Northeast and Central regions, respectively. The terms Q_{source} and Q_{sink} indicate values of net longshore sand transport (LST) entering and exiting each meso-budget, respectively. Negative values for these terms indicate transport to the north. FDEP monuments used for connecting beach calculations are also indicated in these Tables. Numbering of these monuments begins with R-1 for each county.

For the Northeast Region (Table A1), data for meso-budgets 5, 6, and 7 was not available, as indicated by question marks in Table A1. To solve for these unknowns, an intermediate budget was formed by combining these cells and solving Eq. 1. If it is assumed that the unknown P and R values were negligible, and solving for a *Residual* equal to zero, the volume change for cells 5 and 7 can be inferred to be $-228,000$ cu yd/yr. This value was applied in the macro-budget for the Northeast Region. The Northeast region has the largest negative *Residuals* for the meso- and macro-budget scales. The negative *Residuals* indicate that sand sources are missing from the budgets, or that the magnitudes of Q_{source} , Q_{sink} , or ΔV are in error. As examples of sand sources, beach fill and dredged material placement activities may not be included in the available

database, dune erosion may be a significant sand supply, or an offshore supply of sand may need to be considered to balance the budget.

Data for the Central region resulted in a nearly balanced meso-budget, with large negative and positive *Residuals* for meso-budgets 7 (Hutchinson Island) and 9 (Jupiter Island) (Table A2). Because these *Residuals* tend to cancel each other out, it may indicate that values for Q_{source} and Q_{sink} are in error between adjoining meso-budgets.

DISCUSSION

The Northeast and Central regional sediment budgets were developed as a rudimentary, first step in the process of formulating a regional understanding of sediment transport, beach change, and associated engineering activity. The purposes of this application were to (1) exercise and develop the prototype version of SBAS2000, and (2) to discover challenges in developing a regional sediment budget. The following discussion pertains primarily to the latter goal. Findings through the application are as follows:

(1) Regional integration is necessary for consistency. This study benefited greatly by the wealth of coastal data available for the State of Florida, a result of their prescient coastal management and data collection programs. Integration of the existing ISBs and connecting shoreline position data conducted herein highlights the importance of considering sediment budgets on a regional scale. In many instances, budgets between adjacent inlets and the connecting beach did not balance, possibly due to several factors, as discussed below. Regardless of the reason, however, regional integration is essential to ensure that longshore sediment transport rates for adjacent inlet and beach sediment budget cells inlets are compatible.

(2) Shoreline position and beach profile data should be analyzed with care.

(a) Shoreline position data. As presented in Appendix A, the beach profile was assumed to translate parallel to itself, and beach volume change was calculated through a proportionality to shoreline change for all three regions.

Figure 3 shows an example of beach profile comparison in which a *stable* shoreline represents a *net loss* to the beach profile because of dune or bluff retreat. Savage (1990) presents data that indicate roughly 30% of the profiles in St. John's County show opposite bluff and Mean High Water shoreline change, which increases to approximately 55% for Brevard County. Sediment budgets typically strive to represent mid- to long-term conditions (exceeding 5-10 years). However, shoreline position data may be contaminated by seasonal change, storm impacts, in addition to the general mid- to long-term trend, so consideration must be given to distinguishing the mean (trend) from the fluctuations and other sources of contamination of the trend.

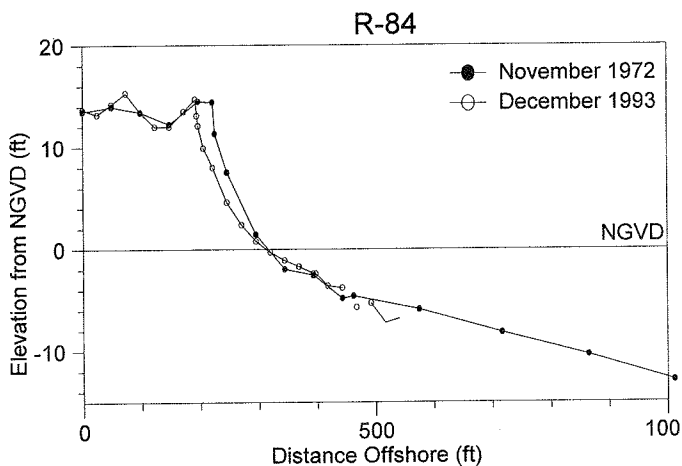


Figure 3. Example of a stable shoreline position (defined as zero NGVD), with apparent net profile loss (Brevard County, Florida)

(b) Beach profile data. To examine the benefits of using profile data in sediment budgets, volume change rates were also calculated by applying the average end method from beach profile data for Dade County, located in the Southeast region, for the period 1980-1998. Table 2 summarizes these results. Although both the shoreline change and the profile change methods have potential limitations and the time periods differ, this comparison

illustrates a difficulty in developing sediment budgets. The sensitivity of the budget to the type of data analysis method should be incorporated into the final regional sediment budget. The profile average end calculation method gives a net volumetric change rate roughly one-quarter of that obtained with the shoreline position method. Possible errors in the shoreline data were discussed above. Errors in the profile data include the methods of measurement. The offshore portion of the profile was measured with a digital echo sounder, which, for a 2000-ft long profile, may result in 55,000 cu yd of error per 1000 ft of beach as compared to a sled survey (Clausner et al 1986). Sleds or the emerging kinematic GPS technology are recommended for measurements of offshore depths. Overlapping wading-depth and offshore data should be checked for consistency (Grosskopf and Kraus 1994).

Table 2. Comparison of Calculation Methods for Dade County (Volumes in 1000s cu yd/year)				
Method	Time Period	Volumetric Change Rate	Beach Fill Placement Rate	Net Volumetric Change
Profile Average End	1980-1998	293	195	98
Shoreline Position (0-NGVD)	1991-1997	667	253	414

- (3) Regional sediment budgets must incorporate uncertainty.** Uncertainty in sediment budgets stems from many causes, as discussed previously and in Kraus and Rosati (1999). Some of the discrepancy between the budgets shown in Appendix A is introduced through uncertainty in the data. As an example, consider the net longshore transport rate that has been cited in the vicinity of the Florida-Georgia border. This value ranges from 600,000 yd³/yr (Dean and O'Brien 1987); 430,000 yd³/yr (Olsen and Associates 1997) and 110,000 to 270,000 yd³/yr \pm 37,000 to 84,000 yd³/yr (Kraus et al 1994). Uncertainty in these reported values (up to a factor of five) impacts adjacent meso-scale sediment budgets and the entire macro-budget. These variations may reflect true uncertainty, limited knowledge, or

inaccuracies in measurements, and they must be identified in the regional sediment budget (by creating several alternative budgets) to clearly communicate the present understanding of regional processes.

- (4) Organization of beach fill and dredged material placement data is needed as a function of monument location.** Organization of Florida's profile data by R-monument lends itself well to a similar structure for beach fill and dredged material placement data. This information is essential for accurate formulation of sediment budgets, as well as for other planning, design, and operation functions of the State and Federal agencies. The FDEP is in the process of cataloging beach fill information. It is recommended that historical, ongoing, and future placement information be organized in a spreadsheet form as a function of county and R-monument, and be available on the FDEP's web site.

SUMMARY AND CONCLUSION

A regional Sediment Budget Analysis System, called SBAS2000, was tested through application to the Northeast and Central regions of the East Coast of Florida. SBAS2000 improves upon SBAS Version 1.0 with enhancements designed for regional applications such as zoom-in/out capability, incorporating geo-referenced images, and integrating shoreline and profile change data and graphs with the sediment budget. Through this application, an initial regional sediment budget was developed for the Northeast and Central regions. This preliminary regional sediment budget can serve as a starting point for developing a balanced regional sediment budget for the entire state. Recommendations were made for improving upon the existing sediment budget methodology.

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APPENDIX A. REGIONAL SEDIMENT BUDGETS

Table A1. Meso- and Macro-Budgets: Northeast Region
(units 1000s cu yd/yr)

Location	FDEP Monu-ments	Q _{source} (LST)	Q _{sink} (LST)	ΔV	P ⁸	R	Residual
1. St. Mary's Entrance ¹		430	-163	405	66	254	0
2. Amelia Island	R30-R70	-163	238	131	153 ¹	0	-379
3. Nassau Sound ²		238	12	250	0	0	-24
4. Little Talbot Island	R11-R22	12	-95 ⁷	107	0	0	0 ⁷
5. Ft. George Inlet ³		-95 ⁷	?	?	0	?	?
6. Huguenot Park	R26-R30	?	?	55	0	0	?
7. St. Johns Entrance		?	78 ⁷	?	?	?	?
8. St. Johns Beaches	R32-R115	78 ⁷	212 ⁵	211	345	0	0 ⁷
9. St. Augustine Inlet ⁵		212	307	-95	22	22	0
10. St. Augustine Beaches	R131-R195	307 ⁵	290 ⁴	20	11	0	8
11. Matanzas Inlet ⁴		290	125 ⁷	165	0	0	0
12. Flagler County, Volusia County to Ponce	R200-R140	125 ⁷	102 ⁶	331	38	0	-270
13. Ponce de Leon Inlet ⁶		102	15	87	0	0	0
14. South of Ponce to Brevard County	R161-Brevard County	15	200 ⁴	77	0	0	-262
Macro-Budget		430¹	200⁴	1516⁹	635¹⁰	276¹⁰	-927¹⁰

¹ Olsen and Associates (1997). ISB extends \pm 4 miles along adjacent beaches.

² Olsen and Associates (1993).

³ No information available.

⁴ Dean and O'Brien (1987).

⁵ Srinivas et al (1996).

⁶ Taylor Engineering (1994).

⁷ Calculated to obtain Residual = 0. Negative value indicates transport to the north.

⁸ From Valverde et al (1999) unless otherwise noted.

⁹ Formulating a budget by combining cells 5, 6, and 7 and assuming that unknown Placement and Removal values = 0 indicates that ΔV for cells 5 and 7 = -228,000 cu yd/yr. This value was applied in the macro-budget.

¹⁰ Assumed unknown values = 0.

Table A2. Meso- and Macro-Budgets: Central Region
(units 1000s yd³/yr)

Location	FDEP Monu-ments	Q _{source} (LST)	Q _{sink} (LST)	ΔV	P ⁷	R	Residual
1. Cape Canaveral	V020-V136	200 ⁵	308 ¹	-108 ⁶	0 ⁸	0 ⁸	0
2. Port Canaveral ¹	-R19	308	-129	437	0	0	0
3. Cocoa Beach south to Melbourne	R20-R215	-129	157	-79	133	0	-74
4. Sebastian Inlet ²	R216-R5	157	108	49	22	22	0
5. Indian River Coast	R6-R23	108	71	83	33	0	-13
6. Ft. Pierce Inlet ³	R24-R44	71	22	84	56	21	0
7. Hutchinson Island	R45-R38	22	209	-10	7	0	-170
8. St. Lucie Inlet ⁴	R39-R53	209	57	152	0	0	0
9. Jupiter Island	R54-R3	57	230	-33	413	0	273
Macro-Budget		200	230	575	664	43	16

¹ Olsen and Associates (1998) and Schmidt (1999).

² Coastal Tech (19xx).

³ Coastal Planning and Engineering, Inc. (19xx).

⁴ Applied Technology & Management, Inc. (1998).

⁵ From Region 1.

⁶ Calculated assuming Residual=0.

⁷ From Valverde et al (1999) unless otherwise noted.

⁸ Assumed.